MEASUREMENT OF PRESSURES BY CARDIAC CATHETERS IN MAN

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THE RECORDING of pressures from the chambers and vessels of the right side of heart in man must usually be done by means of a cardiac catheter connected to a manometer. The dynamic response of such a system can quite easily be made adequate for sufficiently accurate reproduction for most purposes of the pressure pulses in question.[1,5,8] However, serious pressure artifacts, caused by impacts on and motion of the catheter imparted by the heart beat, practically preclude high fidelity pressure pulse recording by this method if conventional catheter-manometer systems are used.[1,4] This study was carried out to obtain data concerning the optimal dynamic response characteristics of cardiac catheter-manometer systems for recording of pressure pulses by venous catheterization in man.

Methods

Pressure pulses, and other physiologic variables were recorded during routine diagnostic cardiac-catheterization procedures,[7] by a photo-oscillographic assembly described elsewhere.[6] In the majority of the experiments, pressures were recorded via the catheter by means of a specially adapted strain gauge manometer.[7] The over-all dynamic response of this catheter-manometer system could be varied instantaneously by a multipole switch, connected so as to allow recording of the pressure pulses interchangeably by three different galvanometers with natural frequencies of 5, 12, and 25 cycles per second, respectively. In part of the experiments the catheter pressures were recorded interchangeably, by turning a stopcock either by a high-frequency capacitance manometer,* or the strain gauge manometer. The resonant frequency and damping characteristics of the catheter-manometer assemblies used were determined at the conclusion of each catheterization procedure by recording the responses of the systems to square wave and variable frequency sine wave pressure variations generated by an electromagnetic hydraulic pressure oscillator described elsewhere.[3,6] Care was taken that the conditions of fluid filling and hydraulic connections between catheter and manometer were identical to the conditions pertaining during the experiment.

The susceptibility of the catheter-manometer systems to pressure artifacts, caused by motion of the catheter, was also studied at the termination of each procedure soon after withdrawal of the catheter tip from the vein. The apparatus used consists of a motor-driven cam, which imparts either a sine wave or a square wave motion to a shaft, to which the tip or shaft of the catheter can be clamped. The sine wave motions were at a frequency of 2 per second and peak-to-peak amplitude of 2 cm. The frequency of the square wave impacts was 1 per second. The pressure artifacts, generated when the catheter was subjected to these motions along the axis of the tip and perpendicular to the tip or the midshaft of the catheter, were studied.

Results

Studies of this type have been carried out during thirty catheterization procedures using strain gauge manometer systems only, and in seventeen procedures using the strain gauge and capacitance manometers interchangeably. The catheters used were of the Cournand type, either 100 or 120 cm. in length, and varying in diameter from size 4 to 7 French.

In general, the dynamic response characteristics of catheters of a given size and length, connected to the strain gauge manometer, were quite closely reproducible from procedure to procedure. This reproducibility was not obtained with the higher frequency capacitance manometer system, in spite of extreme care in attempting to insure minimal compliance of hydraulic connections, and

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*The Lilly Manometer manufactured by the Technitrol Engineering Company, 2751 North Fourth Street, Philadelphia 33, Pennsylvania.

avoidance of entrapment of minute air bubbles.

Catheter-manometer systems with low dynamic response characteristics uniformly produced pressure pulse recordings with less evident distortion by motion artifact than did the higher frequency systems. This difference was especially evident for pressure recordings taken when the catheter was threaded through the beating heart, as is the case for pulmonary-artery wedge, pulmonary arteries and right ventricle pressures.

There was an excellent correlation between the degree of distortion of recorded pressure pulses by motion artifacts, and the amount of pressure artifact caused by sine wave, and impact catheter motions produced by the motor-driven cam apparatus. Figures 1, 2 and 3 show typical results illustrating these findings.

These studies were carried out during and after a cardiac catheterization of a six-year-old girl found to have pulmonic stenosis. Pressures

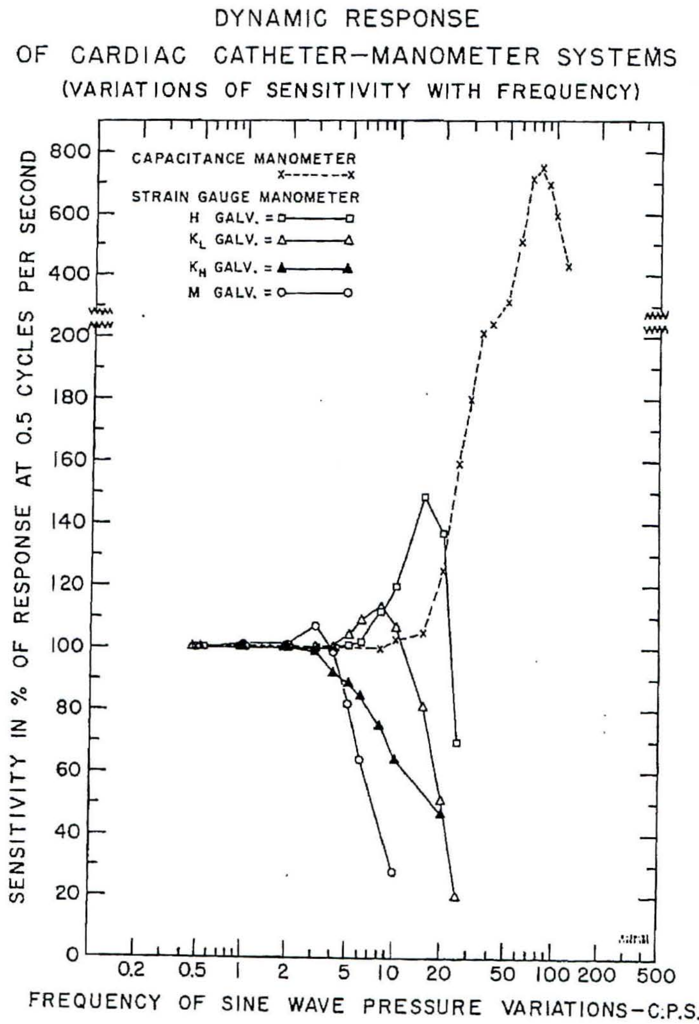

Fig. 1. Variations of sensitivity of cardiac catheter-manometer systems with the frequency of sine wave pressure variations determined immediately after withdrawal of the No. 5 French catheter, 100 cm. long, from the vein (see text for details). The catheter could be connected interchangeably to either a capacitance or a strain gauge manometer. The dynamic response of the strain gauge could be altered interchangeably by connecting it to any one of four different recording galvanometer systems designated as H, K_L, K_H and M.

were recorded via a 100 cm. No. 5 cardiac catheter from the pulmonary-artery wedge, pulmonary artery, and right ventricle by a strain gauge manometer coupled interchangeably to each of four than do motions perpendicular to the axis. Impacts along the axis of the catheter tip caused spikes of pressure varying from 5 mm. of mercury for the overdamped 5-cycle strain gauge system

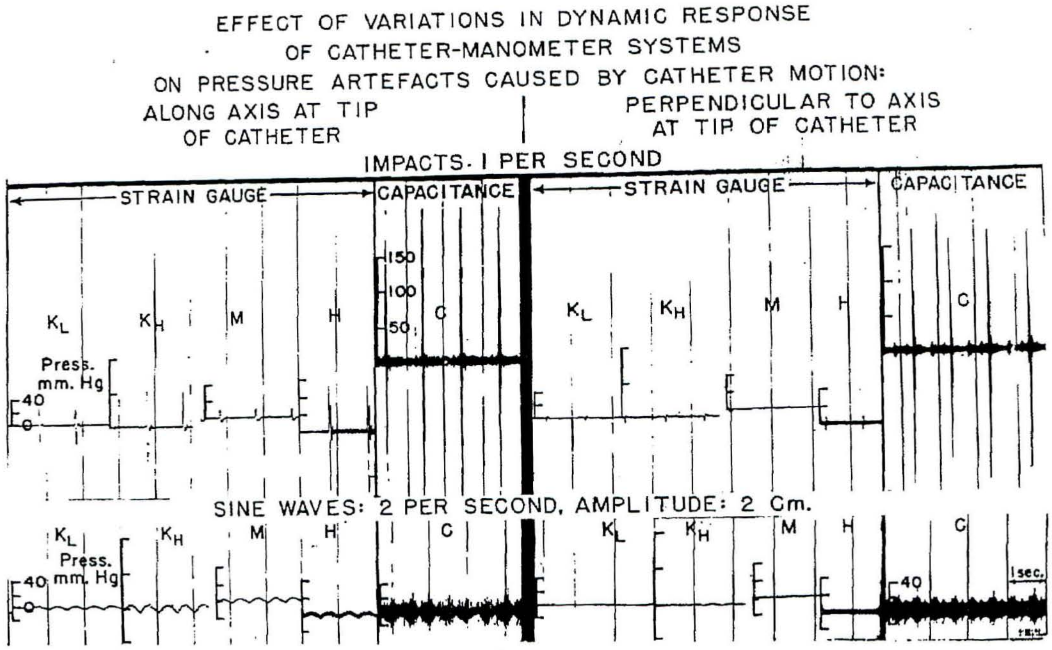

Fig. 2. Effect of variations in dynamic response of cardiac catheter-manometer systems on the pressure artifacts, caused by catheter motion along the axis of the tip of the catheter (left panels), and perpendicular to the axis at the tip of the catheter (right panels). The catheter motions were produced by a motor-driven cam shaft. The dynamic responses of the strain gauge and capacitance manometer systems are shown in Figure 1. Note that the lower frequency strain gauge systems (K_H and M) record less artifact than the 20-cycle system (H), and that the high-frequency undamped capacitance manometer system records continuous high-frequency oscillations probably associated with induced mechanical vibrations in the catheter system. Note also that motions along the axis of the tip of the catheter produce greater pressure oscillations than do identical motions perpendicular to the axis of the catheter tip.

different galvanometer systems, and by a high-frequency capacitance manometer.

The natural frequency of the capacitance manometer system was 90 cycles per second, and that of the strain gauge-catheter system about 20 cycles per second. By use of lower frequency galvanometers the response could be reduced interchangeably to about 10 or to less than 5 cycles per second (Fig. 1). The susceptibility of these catheter-manometer systems to pressure artifacts caused by motion of the catheter is shown in Figure 2. Since the major portion of the pressure artifacts are caused by the acceleration and deceleration of the fluid column within the catheter, induced by motion of the catheter, it is to be expected that motions along the axis of the catheter generate greater reactive pressures to more than 200 mm. of mercury for the underdamped 90-cycle capacitance manometer system. Sine wave motions at 2 per second of 2-cm. amplitude caused smooth 10 mm. of mercury peak-to-peak pressure variations in the 5-cycle system and continuous noise, 10 to 20 mm. of mercury in amplitude, in the 90-cycle capacitance system. Higher frequency catheter-manometer systems were uniformly more susceptible to motion artifacts than the low-frequency systems.

Pressures recorded by these identical catheter-manometer systems from the pulmonary-artery wedge, pulmonary artery and right ventricle are shown in Figure 3. The most artifact-free tracings were obtained by the 5-cycle system. When the catheter was threaded through the heart into the wedge position, the pressure pulses recorded by the 90-cycle capacitance manometer system were obscured by artifacts.

Tracings obtained by the capacitance manometer can be improved by damping so that the response is limited to 5, 10 or 20 cycles per second. The capacitance and strain gauge systems are then about equally sensitive to motion artifacts. Pressure pulse tracings obtained from the pulmonary artery and right ventricle show the least artifact for the 5-cycle system, most for the 20 and intermediate, and about equal artifact for the 10-cycle capacitance and strain gauge systems.

It has been suggested that motion artifacts would be reduced if very small catheters were used or, better still, if pressures were recorded by a small catheter threaded through the standard size cardiac catheter. In our laboratory this has been found not to be the case. The small catheter used was of the Peterson type (145 cm. long, 0.3 mm. I.D., 0.6 mm. O.D.). For pressure recording from the heart it was threaded through a conventional 120 cm. Cournand No. 6 cardiac catheter using a special adapter assembly.

The dynamic response of these systems was determined. The natural frequency of the 0.3 mm. catheter-capacitance system was about 30 cycles per second. For pressure pulse recording the system was damped down to 10 cycles per second, similarly to the standard catheter-strain gauge system. The strain gauge system, recording from

EFFECT OF VARIATIONS IN DYNAMIC RESPONSE
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(Female, 6 yr., Pulmonic Stenosis)

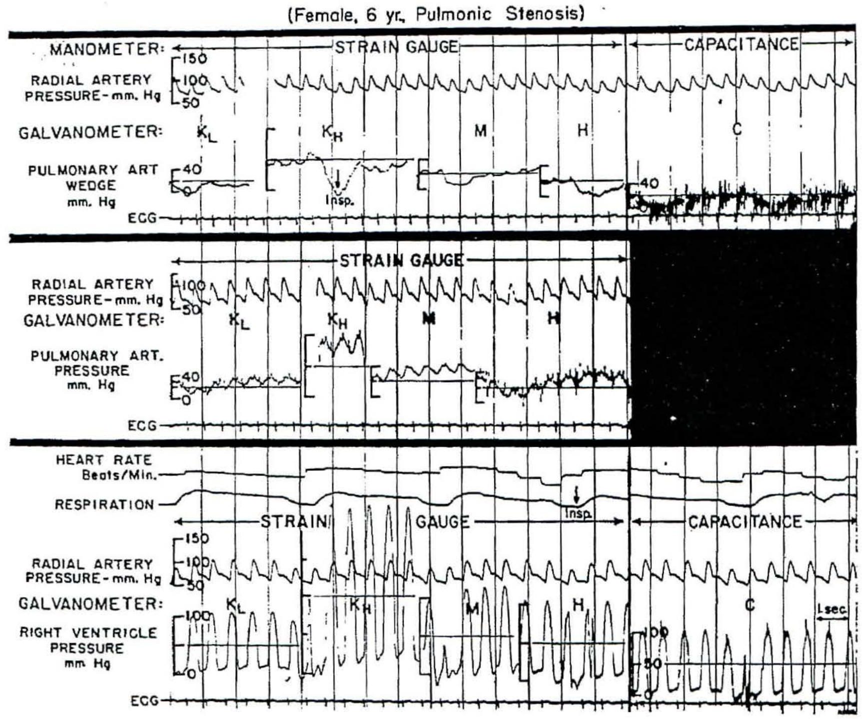

Fig. 3. Effects of variations in dynamic response of catheter-manometer systems on pressure pulses recorded from the pulmonary-artery wedge, pulmonary artery and right ventricle of a six-year-old girl with valvular pulmonic stenosis. The dynamic responses of the strain gauge and capacitance manometer systems are shown in Figure 1. Note that recordings from the lower frequency strain gauge systems (K_H and M), show less evident distortion by artifact than the 20-cycle system (H), and that when the catheter is threaded through the beating heart the pressure pulses in the capacitance manometer recording are almost completely obscured by high-frequency artifact. Note also the correlation between the susceptibility of the various systems to motion artifact shown in Figure 2, and the evident artifact in the pressure pulses recorded by these same manometer systems.

the cardiac catheter containing the small catheter, was the most overdamped of the three systems, having a uniform response out to only 2 cycles per second.

The susceptibility of these systems to motion artifacts was determined also. The overdamped strain gauge system exhibits the smoothest tracing while the small catheter-capacitance manometer system is intermediate between that and the standard catheter-strain gauge system. Actual pressure pulse tracings from the pulmonary artery of the same patient show similar results (Fig. 4), evident motion artifacts on the small catheter-capacitance tracing being intermediate between those seen on the tracings from the two strain gauge-catheter systems.

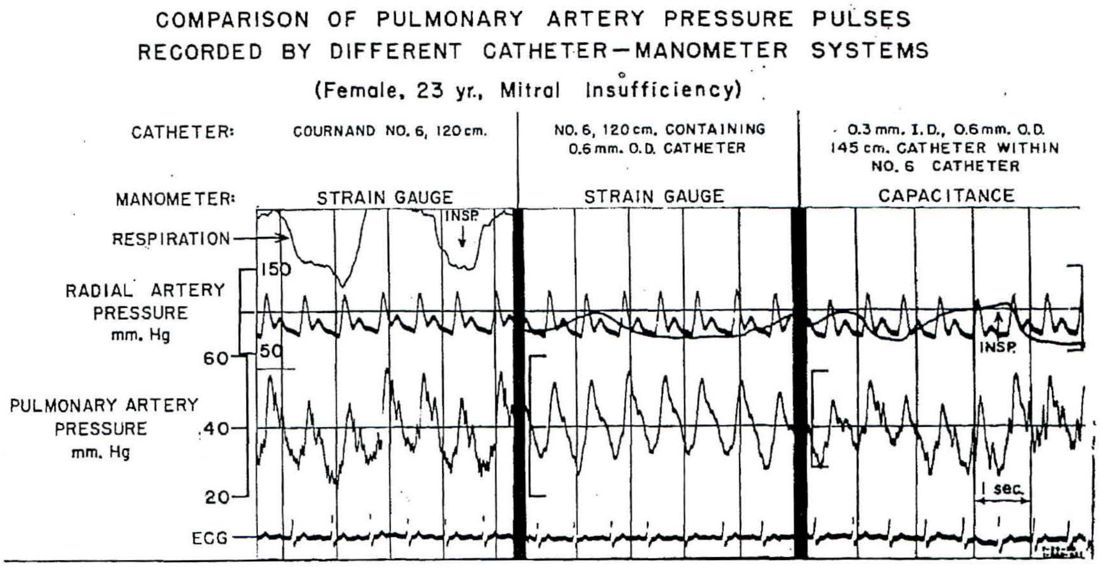

Fig. 4. Comparison of pulmonary-artery pressure pulses recorded by different catheter-manometer systems from a twenty-three-year-old woman with mitral insufficiency. For details concerning the make-up and the dynamic responses and susceptibility to motion artifacts of these three manometer systems, see text. The small plastic catheter was protected from impacts due to the heart action by the No. 6 cardiac catheter through which it was threaded into the pulmonary artery. The pressure pulses recorded by this system (right panel) are nevertheless, still badly distorted by artifact, although somewhat less so than the recordings from the conventional catheter-strain gauge system shown on the left. The frequency response of the overdamped system (strain gauge connected to the No. 6 cardiac catheter containing the small plastic catheter) is probably too low for accurate recording of intracardiac pressure pulses, though the tracings obtained (middle panel) show the least evident distortion.

Comment

These and similar studies have led us to conclude that it is highly improbable that high-fidelity pressure pulse tracings can be recorded via conventional catheters threaded into the beating heart. The degree of evident distortion can be reduced by using relatively low-frequency recording systems with a sharp cutoff in sensitivity to higher frequencies which thus selectively discriminate against the relatively higher frequency motion artifacts. This requirement is, however, mutually antagonistic to the recording of cardiac pressure pulses, since elimination of evident motion artifact requires such a low frequency system that adequate reproduction of the pressure pulses in question may not be possible. Indeed, motions of the catheter at the frequency of the heart beat, induce pressure artifacts at the frequency of the cardiac cycle which may be relatively smooth in contour and fused with the actual pressure pulse in such a way as to be unrecognizable as artifact.

The only solution to this problem known to us at present, is the use of a miniature manometer attached to the intracardiac tip of the catheter. Such a manometer has been made by Gauer and Geinapp after Wetterer's design.[2] Since its moving element has a mass of only 15 mg., reactive forces to acceleration and deceleration of the catheter tip are very small and hence this catheter-manometer system is practically free of motion artifacts when the catheter is moved outside the

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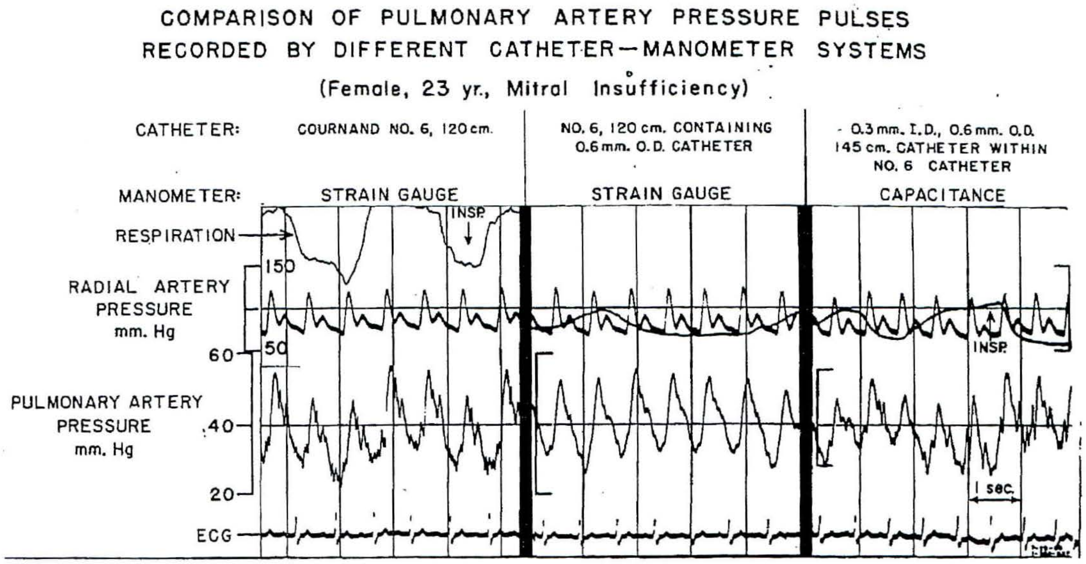

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Summary and Conclusions

An electromagnetic hydraulic pressure oscillator has been used to study the dynamic response characteristics, and a motor-driven cam apparatus to study the pressure fluctuations caused by reproducible sine wave and square wave motions of cardiac catheters connected to strain gauge or capacitance manometer systems. These studies were carried out immediately after use of these identical systems for recording of intracardiac pressure pulses during forty-seven diagnostic cardiac-catheterization procedures in patients with various types of cardiovascular abnormalities.

1. Sine wave motions, along the axis of the tip of the catheter at a frequency of 2 per second and a peak-to-peak amplitude of 2 cm., produce sine wave variations of pressure at this frequency and with a peak-to-peak amplitude of about 10 mm. of mercury. This motion of the catheter tip resembles that usually seen to some degree at cardiac catheterization, especially when the catheter tip is in the pulmonary artery. Sine wave motion perpendicular to the axis of the tip of the catheter did not produce pressure fluctuations of practical significance.

2. Square wave motions (impacts) produce high-frequency pressure variations of greatest magnitude when the impact is directed along the axis of the tip of the catheter. The amplitude of the recorded pressure variations induced by square wave motion of the catheter (impacts) varied inversely with the frequency response of the catheter-manometer systems used. Impacts of the catheter produced much less pressure fluctuation when in a direction perpendicular to the axis of the catheter than when directed along the axis of the catheter.

3. A close correlation was demonstrated between the susceptibility of cardiac catheter-manometer systems, to pressure artifacts induced by motion of the catheter outside of the body, and the degree of distortion by artifact of pressure pulses recorded by the same catheter system from the beating heart.

4. Catheter-manometer systems, with a uniform dynamic response out to 5 to 10 cycles per second with a sharp cutoff in sensitivity to higher frequencies, were least susceptible to the higher frequency pressure artifacts induced by catheter motion, and likewise produced pressure pulse recordings with the least evident distortion by artifacts.

5. Pressure pulses, recorded by conventional catheters threaded through the beating heart, should be regarded with a high index of suspicion, since the lower frequency artifact induced by motion of the catheter synchronous with the heart beat, may be of such character and be fused with each pressure pulse in such a manner as to be unrecognizable as artifact.

6. Recording of pressures by a small (0.3 mm. I.D.) catheter threaded through a conventional cardiac catheter reduces slightly but not to a sufficient degree the artifact present in pressure pulse recordings from within the heart.

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